TABLE 1.—*Analysis of variance (mean squares x 10³).*[1]

Source	df	Glutamic acid	Aspartic acid	Pyro-glutamic acid	Malic acid	Citric acid	Phos-phoric acid	Oxalic acid
1961								
Varieties	4	0.49*	0.13*	0.86[2]	1.02*	2.86*	0.76*	0.014
Locations	5	1.94*	0.22*	1.71*	5.30*	38.68*	0.16*	0.047*
Var. x Loc.	18[3]	0.35	0.26	0.37	0.60	3.01	0.13	0.031
Replicates	1	0.69	1.25	3.44	0.01	5.08	0.00	0.061
Residual	25[3]	0.13	0.04	0.33	0.06	0.28	0.01	0.015
1962								
Varieties	4	0.85*	0.19*	0.50[2]	2.19*	9.80*	0.12*	0.020*[4]
Locations	5	1.03*	1.03*	1.25*	6.22*	43.29*	0.58*	0.080*
Var. x Loc.	20	0.11	0.08	0.40	0.35	5.09	0.07	0.028
Replicates	1	0.03	0.08	2.55	0.31	0.20	0.34	0.001
Residual	29	0.01	0.01	0.23	0.10	0.57	0.02	0.007
1963								
Varieties	4	0.44*	0.16	1.63	0.42	1.15	0.17*	0.051*
Locations	5	0.26*	0.09	1.28	2.57*	11.59*[4]	0.12*	0.025
Residual	19[3]	0.04	0.21	0.98	0.33	3.96	0.04	0.013

*Denotes varieties and locations significant at the 5% level (F-test); results of F-tests based on dry-weight data were similar except where noted.
[1]Based on fresh-weight data.
[2]Significant at the 5% level when based on dry-weight data.
[3]Degrees of freedom corrected for missing data.
[4]Not significant at the 5% level when based on dry-weight data.

significant. The averages and the results of the Multiple Range Test are given in Table 2. Because of the large volume of data, Tables 1 and 2 list only the results of calculations made on a fresh-weight basis; results on a dry basis were similar. Both fresh- and dry-basis tables of individual data, and the results of dry-basis Multiple Range Tests, will be furnished upon request.

Table 2 shows that in any given year varieties can be found which, when averaged over the six locations, are significantly higher or lower in particular acids than all or most of the other varieties. A similar statement can be made about locations. In addition, several varieties and locations are high or low in particular acids for 2 or 3 years, although the differences may not be statistically significant in all 3 years. The more pronounced examples of this among the varieties are Cobbler, high in glutamic and low in phosphoric and total acids (for total acids see Figs. 1 and 2); Russet Burbank, high in malic; Kennebec, high in citric; Katahdin, low in aspartic acid. Examples of this among the locations are Maine, high in malic and low in glutamic and phosphoric acids; Idaho, high in oxalic; Long Island, low in malic, citric, and total acids.

In order to facilitate comparison of the three crop-years, average data calculated on a fresh-weight basis are presented as yearly profiles (Figs. 1 and 2). In these figures the "curves" do not represent functions of a variable, but connect variety or location means of the same crop in order that the three crops may be compared as to the sequence

TABLE 2.—*Mean acid concentrations in varieties and locations; per cent on fresh weight.*[1]

Acid	Varieties[2] 1961	Varieties[2] 1962	Varieties[2] 1963	Locations[3] 1961	Locations[3] 1962	Locations[3] 1963
Glutamic	COB .055 a	COB .077 a	COB .077 a	RRV .073 a	PEN .079 a	PEN .073 a
	RUS .052 ab	PON .060 b	RUS .064 b	IDA .054 b	RRV .065 b	LI .071 a
	KEN .051 ab	KEN .059 b	KAT .062 bc	PEN .045 bc	LI .065 b	RRV .062 b
	PON .043 bc	RUS .058 b	PON .060 bc	WIS .042 c	IDA .059 c	WIS .062 b
	KAT .040 c	KAT .057 b	KEN .054 c	MAI .039 c	WIS .058 c	IDA .059 b
				LI .034 c	MAI .048 d	MAI .055 b
Aspartic	PON .068 a	RUS .047 a	RUS .048 a	PEN .070 a	PEN .060 a	MAI .047 a
	KEN .064 ab	COB .047 a	COB .043 a	LI .069 a	RRV .045 b	PEN .043 a
	COB .064 ab	KEN .043 b	KEN .042 a	IDA .063 b	WIS .043 b	RRV .042 a
	RUS .062 b	KAT .039 c	PON .036 a	MAI .061 b	IDA .043 b	IDA .037 a
	KAT .059 b	PON .038 c	KAT .036 a	RRV .060 b	LI .036 c	LI .037 a
				WIS .059 b	MAI .030 d	WIS .036 a
Pyroglutamic	KEN .088 a	RUS .069 a	KEN .124 a	LI .101 a	IDA .073 a	WIS .127 a
	KAT .081 ab	KAT .066 ab	KAT .122 a	PEN .087 ab	RRV .068 ab	LI .121 a
	PON .080 ab	KEN .060 ab	RUS .111 a	RRV .075 bc	PEN .064 ab	IDA .112 a
	RUS .077 ab	PON .057 ab	PON .102 a	IDA .070 bc	LI .064 ab	RRV .095 a
	COB .065 b	COB .053 b	COB .082 a	MAI .070 bc	MAI .056 b	MAI .093 a
				WIS .068 c	WIS .041 c	PEN .093 a
Malic	PON .115 a	RUS .099 a	KAT .084 a	RRV .139 a	MAI .113 a	MAI .114 a
	RUS .112 a	KAT .087 b	RUS .081 a	MAI .122 b	IDA .097 b	IDA .079 b
	COB .103 b	PON .079 c	KEN .073 a	WIS .107 c	RRV .095 b	RRV .071 bc
	KAT .096 c	KEN .076 c	PON .067 a	IDA .094 d	WIS .071 c	WIS .065 bc
	KEN .094 c	COB .062 d	COB .063 a	LI .084 e	PEN .063 c	PEN .054 bc
				PEN .080 e	LI .046 d	LI .052 c

Citric	KEN .427 a	KEN .426 a	RUS .391 a	WIS .514 a	IDA .471 a	RRV .416 a
	RUS .414 ab	PON .413 a	KEN .377 a	IDA .430 b	PEN .467 a	IDA .398 a
	KAT .410 b	COB .391 b	KAT .371 a	MAI .404 c	RRV .384 b	WIS .376 a
	COB .401 b	RUS .371 c	COB .363 a	RRV .395 c	WIS .382 b	PEN .374 a
	PON .386 c	KAT .357 c	PON .350 a	PEN .375 d	MAI .339 c	MAI .368 a
				LI .328 e	LI .308 d	LI .277 b
Phosphoric	KAT .061 a	KEN .050 a	KAT .057 a	IDA .059 a	IDA .056 a	LI .058 a
	KEN .059 ab	KAT .048 a	KEN .049 b	PEN .057 ab	RRV .053 a	IDA .048 b
	PON .058 b	PON .048 a	PON .048 b	WIS .055 bc	LI .048 b	WIS .047 b
	COB .046 c	RUS .044 b	RUS .045 b	LI .052 cd	PEN .043 c	RRV .046 b
	RUS .044 c	COB .042 b	COB .043 b	MAI .050 de	WIS .039 cd	MAI .045 b
				RRV .048 e	MAI .037 d	PEN .045 b
Oxalic	KEN .022 a	COB .023 a	KEN .020 a	IDA .024 a	PEN .026 a	IDA .019 a
	RUS .021 a	RUS .023 a	RUS .017 ab	WIS .022 ab	IDA .026 a	PEN .017 ab
	COB .020 a	KEN .023 a	KAT .016 ab	MAI .021 ab	LI .022 b	WIS .017 ab
	PON .020 a	KAT .023 a	PON .014 b	LI .019 b	RRV .021 bc	RRV .015 ab
	KAT .020 a	PON .020 b	COB .013 b	PEN .019 b	WIS .020 bc	MAI .014 ab
				RRV .018 b	MAI .019 c	LI .013 b

[1]Means followed by same letter not significantly different from each other, 5% level.
[2]COB - Cobbler, KAT - Katahdin, KEN - Kennebec, PON - Red Pontiac, RUS - Russet Burbank.
[3]IDA - Idaho (Aberdeen), LI - Long Island (Riverhead, New York), MAI - Maine (Presque Isle), PEN - Pennsylvania (State College), RRV - Red River Valley (East Grand Forks, Minnesota), WIS - Wisconsin (Sturgeon Bay).

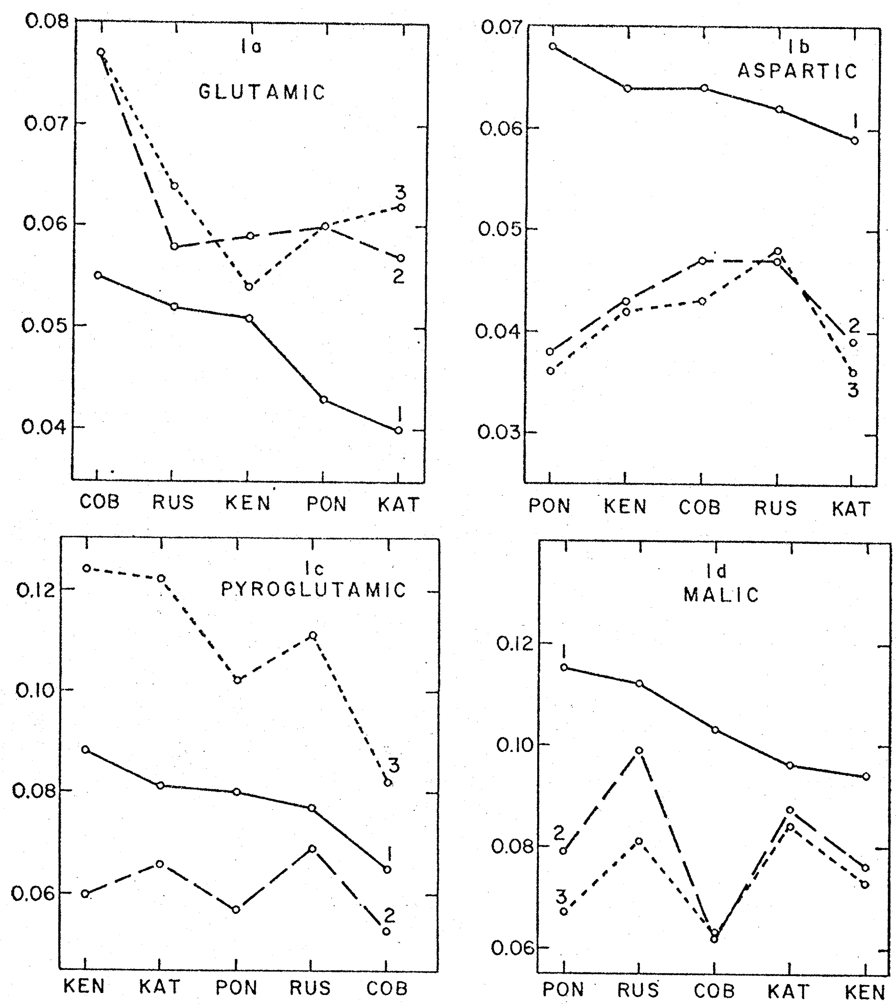

FIG. 1.—Profiles of acid concentrations (%, fresh basis) in three crops of five varieties. 1 = 1961, 2 = 1962, 3 = 1963. For abbreviations see Table 2, footnote 2.

of varieties or locations when arranged in order of acid content. With some acids it was necessary to choose different scales for the variety and location profiles because of differences in range and the exigencies of illustration. With this is mind, no difficulties should arise in making the above-mentioned comparison. The profiles for "total acids" included in the figures were obtained by adding the concentrations of the known acids. Values for 1961 are shown in order of decreasing magnitude; for 1962 and 1963, varieties and locations are in the same order as for 1961 rather than in order of magnitude. This results in rather jagged profiles for most of the acids, but notable for 1962 and 1963 is the remarkable

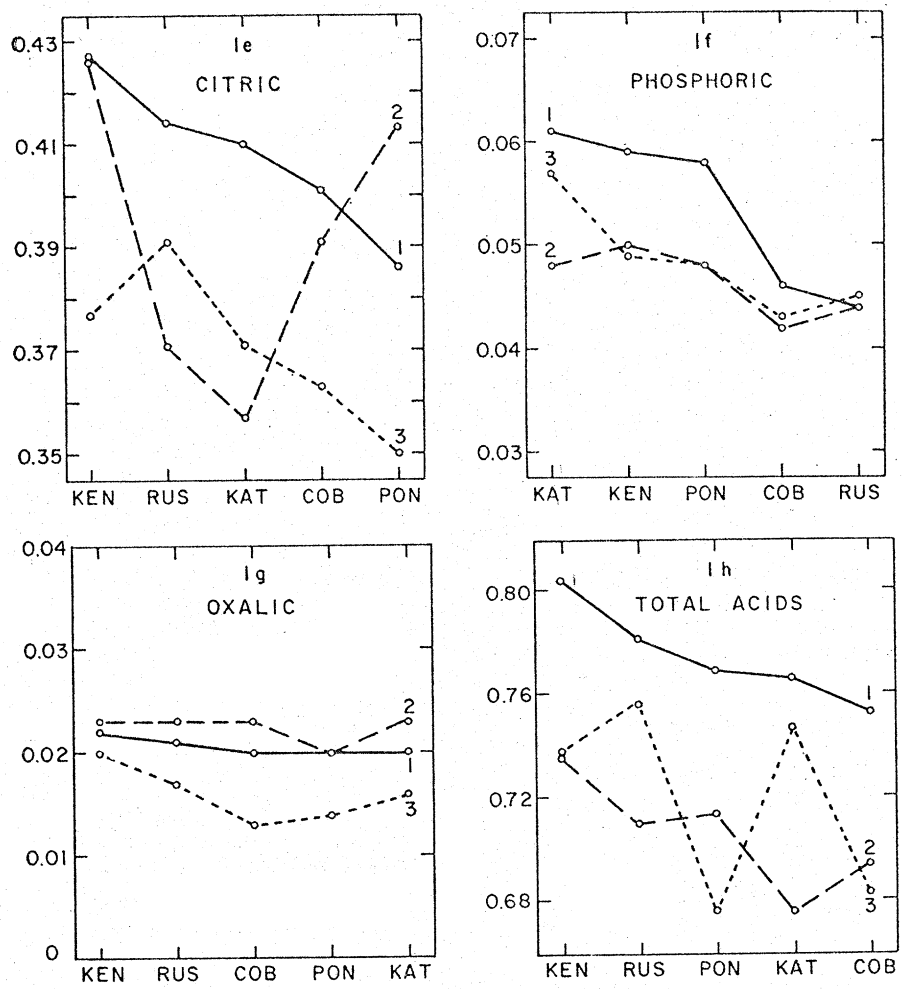

FIG. 1.—*Continued.*

similarity in profile for almost all acids, indicating a high degree of consistency in relative acid concentrations. This also indicates greater reliability for results for 1963, which were not as often significant by the Multiple Range Test (Table 2) as results for other years, because samples for 1963 were not run in replicate.

Not only does the 1961 crop differ in profile shape, but it is also higher in total acids and in most of the individual acids than the other crops. It is higher in aspartic, malic, phosphoric, and the unidentified acid. It is also high in citric, with some exceptions among the locations. The 1961 crop lies between the other two in pyroglutamic and oxalic acid and is low only in glutamic acid. Acid concentrations in 1962 and 1963 are about equal in most cases.

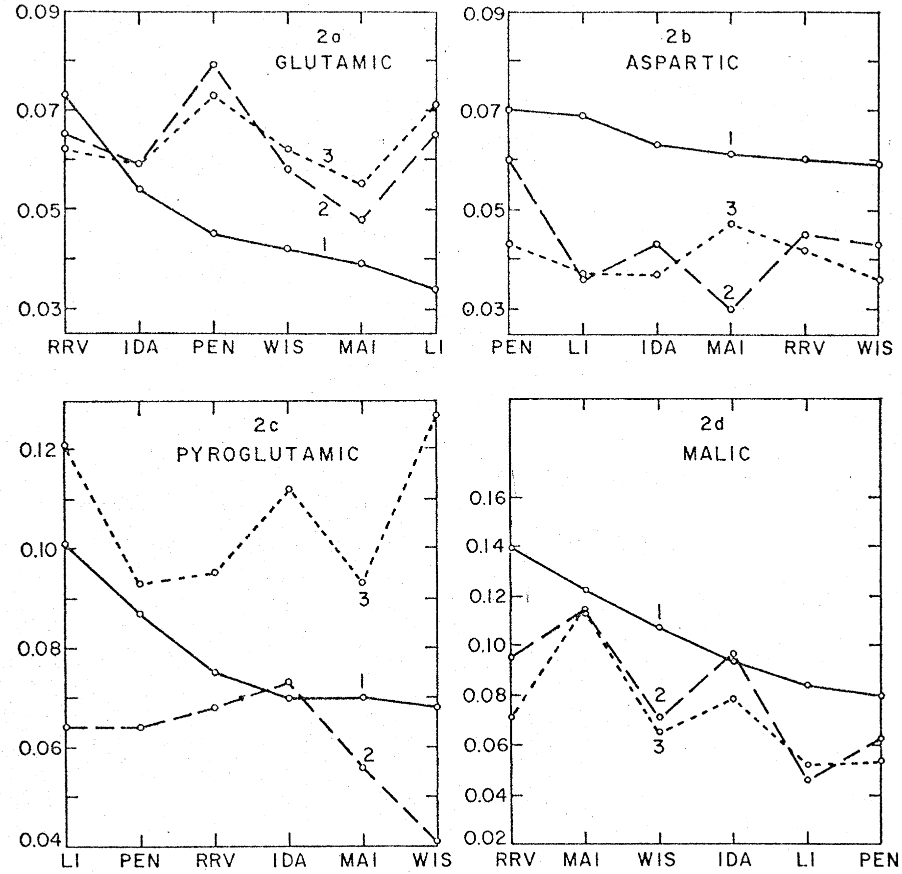

FIG. 2.—Profiles of acid concentrations (%, fresh basis) in three crops of potatoes from six locations. 1 = 1961, 2 = 1962, 3 = 1963. For abbreviations see Table 2, footnote 3.

The above-mentioned unidentified acid ranged from approximately 1.2 milliequivalents per 100 g in Russet Burbanks to approximately 1.6 milliequivalents per 100 g (fresh basis) in Katahdins. Its profiles for varieties resembled each other for all 3 years, but in the case of the location averages only the profiles for 1962 and 1963 were similar. As with most of the other acids, there was more of the unidentified acid present in 1961 than in the other 2 years.

An indication of the reason for the differences between the 1961 crop and the other two crops is shown in Table 3, which lists the deviations from the normal total rainfall and normal average temperature, for the months May through August, in the localities where the potatoes were grown. In all areas, except Sturgeon Bay, Wisconsin, rainfall in 1961 was either the highest or the lowest of the three years. Deviations from normal temperature were more pronounced in the western localities and in 1961 were in a direction tending to aggravate the effects of the drought

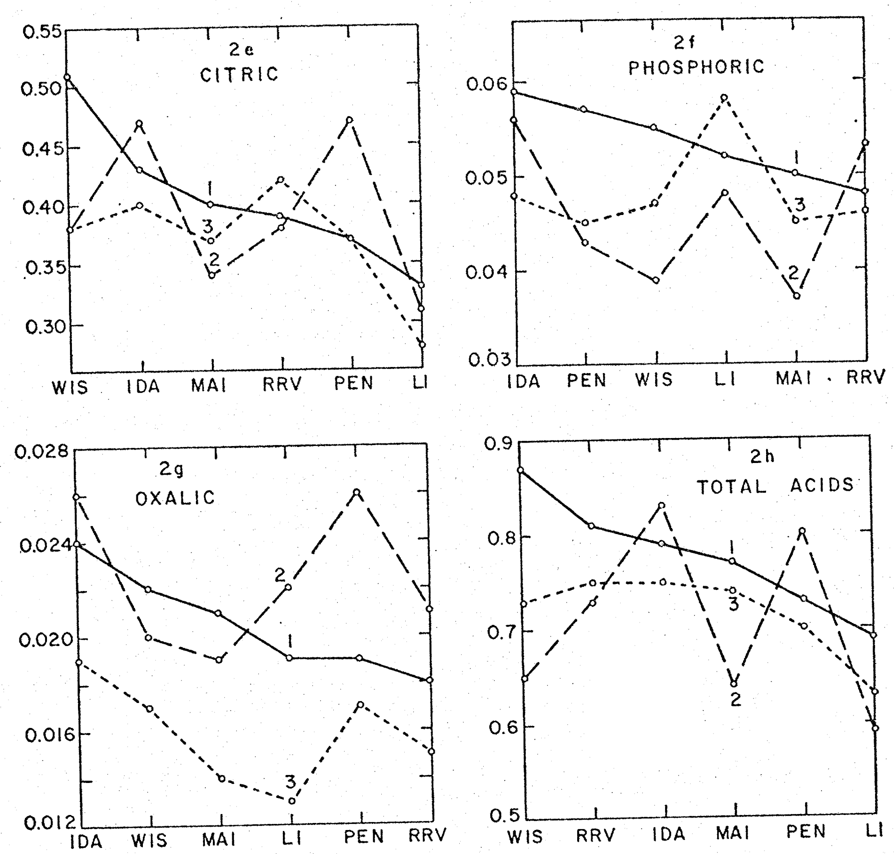

FIG. 2.—*Continued.*

then occurring. These facts help explain the differences in profiles but not necessarily the tendency of 1961 potatoes to be higher in acid concentrations, since the deviations from normal were in two directions, eastern localities having more rain than normal and western localities less. Weather data are presented in this paper for possible future reference and are not intended to indicate that any numerical relation has been presently found between the data and acid concentrations.

It appears so far that variety, location, and differences in weather conditions in different years all have an influence on the concentration of acids in potato tubers. With the object of gaining some idea about the relative importance of these factors, the data were given a furher statictical treatment which assumed that varieties, locations, and years were variables randomly selected from a larger population. Conclusions derived from this treatment, however, would be expected to be most applicable to commercial fall-crop varieties and growing areas. Since the 1963 samples were not run in replicate, the averages of each set of replicates in 1961 and 1962 were used as raw data for these years. Per cent of the total variance contributed by each of the variables was estimated.

TABLE 3.—*Deviations from normal rainfall and temperature.*[1]

Location	Rain Normal[2]	Rain 1961	Rain 1962	Rain 1963	Temperature Normal[2]	Temperature 1961	Temperature 1962	Temperature 1963
Maine	13.8	+4.9	+2.3	+1.6	60.5	—0.7	—1.5	+0.2
Long Island	14.2	—0.1	—1.1	—1.5	68.6	—1.2	—2.4	—1.1
Pennsylvania	15.3	+0.7	—9.2	—2.3	67.6	—1.6	+0.2	—1.5
Wisconsin	11.9	+1.3	+6.6	—3.5	62.7	—0.3	—0.3	—0.1
Red River Valley	11.4	—6.1	+1.7	+1.0	62.3	+2.8	+0.9	+2.5
Idaho	2.4	+0.6[4]	+2.2	+2.5	63.5	+2.0	—3.2	—2.4

[1]Calculated from data obtained from Weather Bureau publications.
[2]Normal total rainfall (inches) for May through August.
[3]Normal average temperature (°F) for May through August.
[4]Over 70% of this fell in May. Rain scanty during the summer.

TABLE 4.—*Per cent of total variance contributed by variables and interactions.*[1]

Source	df	Glutamic acid	Aspartic acid	Pyroglutamic acid	Malic acid	Citric acid	Phosphoric acid	Oxalic acid
Varieties	4	13.7	0.2	5.8	3.2	0.0	21.6	3.9
Locations	5	7.8	1.0	0.1	35.9	25.9	2.5	7.7
Years	2	19.9	51.3	42.9	21.9	1.2	8.3	34.9
Var. x Loc.	20	0.0	4.9	0.0	0.0	4.1	8.6	0.0
Var. x Years	8	2.0	0.0	0.0	2.0	0.0	4.1	0.0
Loc. x Years	10	25.2	6.7	7.6	8.1	26.1	20.6	1.7
Residual	37[2]	31.4	35.9	43.6	28.8	42.8	34.4	51.8

[1]Based on fresh-weight data.
[2]Degrees of freedom corrected for missing data.

Results calculated on a fresh-weight basis are shown in Table 4; dry-basis results were similar. The table indicates that for some of the acids (glutamic, pyroglumatic, and phosphoric) variety was the more important factor; for other acids (malic, citric, and oxalic) location was more important. Also, in accordance with what one might expect from the yearly profiles, years were a relatively important factor with all acids except citric and phosphoric. These conclusions on the relative importance of different factors in determining acid concentration must be considered tentative because of the limited nature of the data. However, they should be of interest for comparison with other work which may be done in the field.

SUMMARY

A study was made of the variation of glutamic, aspartic, pyroglutamic, malic, citric, phosphoric, and oxalic acid concentrations in Cobbler, Katahdin, Kennebec, Red Pontiac, and Russet Burbank potatoes. Each variety was grown in six different locations (Idaho, Maine, Pennsylvania, Wisconsin, Long Island, and the Red River Valley) during the years 1961 through 1963.

The varieties and locations studied were found to have a statistically significant effect in determining concentrations of the various acids. The few exceptions to this were almost entirely in 1963, probably because replicates were not run that year. The more pronounced trends in acid concentration noted for all 3 years included, among the varieties, Cobbler, high in glutamic, low in phosphoric; Russet Burbank, high in malic; Kennebec, high in citric; Katahdin, low in aspartic. Among the locations were Maine, high in malic, low in glutamic and phosphoric; Idaho, high in oxalic; Long Island, low in malic and citric.

The years 1962 and 1963 strongly resembled each other in relative concentration of the various acids but differed from 1961, a year in which abnormal weather conditions prevailed.

In a separate statistical treatment in which the importance of variety, location, and year in determining acid concentrations was estimated, indications were obtained that for some acids (glutamic, pyroglutamic, and phosphoric) variety was the most important factor; for other acids (malic, citric, and oxalic) location was more important. Also, years were a relatively important factor with all acids except citric and phosphoric.

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Resumen

Se hizo un estudio de la variación en concentración de los ácidos glutámico, piroglutámico, malico, cítrico, fosfórico, y oxálico en las variedades de papa Cobbler, Katahdin, Kennebec, Red Pontiac, y Russet Burbank. Cada variedad se cultivó en seis localidades diferentes (Idaho, Maine, Pennsylvania, Wisconsin, Long Island, y la Red River Valley) durante los ános 1961 - 1963.

Las variedades y localidades tuvieron un efecto estatisticamente significativo en la determinacion de la concentración de los ácidos. Las pocas excepciones a esto fueron casi todos durante el año 1963, posiblemente porque no hubo replicaciones en ese año. Los más pronuciados tendencias en concentraciones de ácido anotado para los tres años incluidos, entre los variedades, Cobbler, alto en ácido glutanico, bajo en fosfórico; Russet Burbank, alto en málico; Kennebec, alto en citricó, Katahdin, bajo en aspártico. Entre los localidades, Maine estuvo alto en málico, bajo en glutámico y fosfórico; Idaho alto en oxálico; Long Island bajo en málico y en cítrico.

Los años 1962 y 1963 fueron muy similares en concentración relativa

de los ácidos, pero diferente de 1961, un año en lo cual prevalecieron ambientales anormales.

En un tratamiento estadístico en lo cual fue estimado la importancia de variedad, localidad, y año en determinación de concentración de ácido, se encontró indicaciones que para alqunos ácidos (glutámico, piroglutámico, y fosfórico) variedad era lo más importante: para otros ácidos (málico, citricó, y oxálico) localidad era mas importante. Además, año fue un factor relativamente importante con todo los ácidos con excepción del cítrico y fosfórico.

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CHEMICAL COMPOSITION OF POTATOES. VI. EFFECT OF VARIETY AND LOCATION ON ACID CONCENTRATIONS[1]

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INTRODUCTION

In recent years, with the increasing use of chromatographic techniques, knowledge of potato composition has been greatly extended. Of special interest are constituents that play a role in problems of the potato processing industry. The involvement of amino acids and reducing sugars in non-enzymatic browning (Maillard reaction) has been known for some time. Andreotti (1) showed that, among the amino acids, serine and glutamic and aspartic acids are most active. Some non-nitrogenous acids also take part in this type of browning. Haas and Stadtman (4), Anet and Reynolds (2), and Andreotti (1) showed this for malic and citric acids, Lewis et al. (9) and Kapur et al. (8) for oxalic and other acids. Chlorogenic acid and citric acid are involved in the problem of after-cooking blackening (Hughes and Swain (6), Heisler et al. (5)).

One approach to ameliorating these problems could lie in either growing or selecting potatoes high or low in particular constituents, for example high in citric acid and low in chlorogenic acid for the purpose of controlling after-cooking blackening. To be able to do this it is important to know how constituent concentrations vary among different varieties and growing areas and to know in general the relative influence of varietal and environmental factors. This matter has been little studied with potato constituents. Stevenson et al (12) found that there are varietal differences in total solids content, but that environmental influences are often more important than varietal. Hyde (7) studied variety and location effects on ascorbic acid concentrations and lists earlier work on the subject. He found that varietal differences in concentration are relatively unaffected by location. As part of a larger study being carried out at this Laboratory on the effects of variety and place of growth on the concentrations of potato constituents, the concentration of glutamic, aspartic, pyroglutamic, malic, citric, oxalic, and phosphoric acids in potatoes from several important varieties and growing areas were investigated.

MATERIALS AND METHODS

Five commercially important varieties of fall-crop potatoes (Cobbler, Katahdin, Kennebec, Red Pontiac, and Russet Burbank) were chosen for investigation. These varieties were grown at each of six State Experiment Stations in 1961 through 1963 (see Table 2, footnote 3). Cultural conditions were similar to those typically employed in the various locations. Upon harvest in late September or early October a 100-pound sample of each variety was randomly selected. All varieties at each location

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were stored the same length of time at 40 F (one week to one month) and then shipped to this Laboratory by Railway Express. Upon arrival they were sampled, peeled, and made into a slurry with ethanol. Portions of the slurry were taken for determining solids by oven-drying and for making extracts of the potato acids. The methods of sampling and extraction were those described by Talley et al. (13) except that the potatoes were not classified according to specific gravity. The extracts from three representative samples of each batch of potatoes were stored in a cold room at 34-38 F until ready for analysis. Each contained 20% ethanol by weight to prevent alcoholic fermentation.

In order to obviate the effects of any changes in acid content during storage of the extracts, the order of analysis of the different extracts was randomized with the help of a table of random numbers. For the same reason the three extracts from each batch of potatoes were classified into an A, B, and C series, and after analysis of the A series was complete the B series was analyzed in the same order. The C samples were kept as a reserve. For the 1963 crop, only the A series was run. Because 2 days were required for the analysis of each extract, approximately 2 to 3 months elapsed between analyses of an extract in the A series and the replicate extract in the B series. Little or no change in acid concentrations occurred during this interval, as indicated by the replicate values. The acids were determined by titration after gradient elution from an ion-exchange column (Schwartz 10, Schwartz et al. 11). The same batch of ion-exchange resin was used for all 3 years. Of the acids determined, pyroglutamic is probably, at least in part, an artifact derived from glutamine. The term "total acids," as used below, refers to the sum of the concentrations of the known acids; an unidentified acidic material which was eluted last from the ion-exchange column is not included.

Results and Discussion

The data were subjected to a statistical analysis of variance by two methods. For both, missing plot values (Idaho Katahdins and Pontiacs in 1961, Red River Valley Katahdins in 1963) were estimated in order to make possible a complete factorial treatment of the data, and the degrees of freedom in the error terms were adjusted for the missing data. In the first method, upon which the results shown in Tables 1 and 2 are based, a separate analysis was made for each year. Since in this case the purpose was to compare important varieties and locations rather than to regard the varieties and locations selected as a random sample, residual mean squares were used in the F-ratio denominators when determining significance. The results of this analysis of variance are given in Table 1. In all but a few cases variety and location mean squares were found to be significant at the 5% level for the years 1961 and 1962. In 1963, significance was found in only half the cases possibly because replicates were not run that year.

The means computed for each variety by averaging the acid concentrations of potatoes grown in all six locations, and for each location by averaging the results for all five varieties grown therein, are subsequently referred to simply as "averages" or "average values." Duncan's Multiple Range Test (Duncan (3) was applied to these values in order to determine whether the differences between the individual averages were